

RADIO TRANSMISSION BETWEEN TWO SUBMERGED SUBMARINES

Dr. O. Norgorden and Dr. R. B. Quinn

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Mr. R. B. Meyer, Head, Communication Section
Mr. L. A. Gebhard, Superintendent, Radio Division II



NAVAL RESEARCH LABORATORY

CAPTAIN H. A. SCHADE, USN, DIRECTOR

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ABSTRACT

Experiments have been conducted with two submerged submarines which demonstrate that a radio wave propagation path is possible, involving transmission over the horizontal distance above the surface instead of directly through the sea water to the submerged receiver, which holds the prospect of communication over militarily useful distances. Without special transmitting, receiving, or antenna coupling equipment, and without optimum design of antennas or choice of frequency, a transmission distance of 3000 yards was realized, at which point the signal was weaker than the high local noise.

PROBLEM STATUS

This is a report of the investigation of one phase of the Underwater Radio Problem. The problem is continuing.

AUTHORIZATION

NRL Problem Number R11-02R.

RADIO TRANSMISSION BETWEEN TWO SUBMERGED SUBMARINES

INTRODUCTION

The ability of a completely submerged submarine to receive very-low-frequency radio signals has been known and utilized for many years. A comprehensive analysis has been made of the loop antenna for the reception of radio signals when the loop is submerged in sea water.¹ Considerable progress has been made toward obtaining the maximum sensitivity for the reception of very-low-frequency radio signals by completely submerged loop antennas.

Radio transmission in sea water between two submerged positions suffers such severe attenuation that useful applications have not been considered feasible. However, some advances have been made in the field of transmission of radio signals from completely submerged antennas and this progress coupled with the possibility of transmission from one submerged antenna to another submerged antenna over the sea-water-to-air-to-sea-water path holds promise for submerged communication. Such a path is subject to far less sea water attenuation and communication between two completely submerged submarines appears possible provided the transmitting and receiving antennas are both relatively close to the surface. For this propagation path the high sea water attenuation is limited to a value corresponding to the sum of the depths of the transmitting and receiving antennas, while the propagation laws governing transmission along the horizontal path above the surface are the same as for normal or regular waves along the surface of the earth.

Experimental transmissions embracing these factors were conducted with two submarines, the U.S.S. MEDREGAL (SS480) and the U.S.S. SEA LEOPARD (SS483), operating from the Key West Naval Base during the period 17 to 19 November 1947. Communication between submerged submarines has received the unremitting attention of the Navy; however, the Key West experiments rank as one of the first successful attempts to communicate by radio between two completely submerged submarines underway. The principal aim of the experiment

¹ O. Norgorden, "The Submerged Reception of Radio Frequency Signals,"
NRL Report R-1669, 2 December 1940

was to demonstrate the feasibility of such a radio system rather than to try to obtain the maximum possible range. The experimental arrangement employed is not to be regarded as being proposed for operational use.

ANTENNA INSTALLATIONS

The U.S.S. SEA LEOPARD was chosen to be the receiving submarine. Its type 66097 low-frequency receiving loop was remounted above the shears, between the periscopes, with the plane of the loop parallel to the centerline of the ship. The remounted loop may be seen in Figure 1. The top of

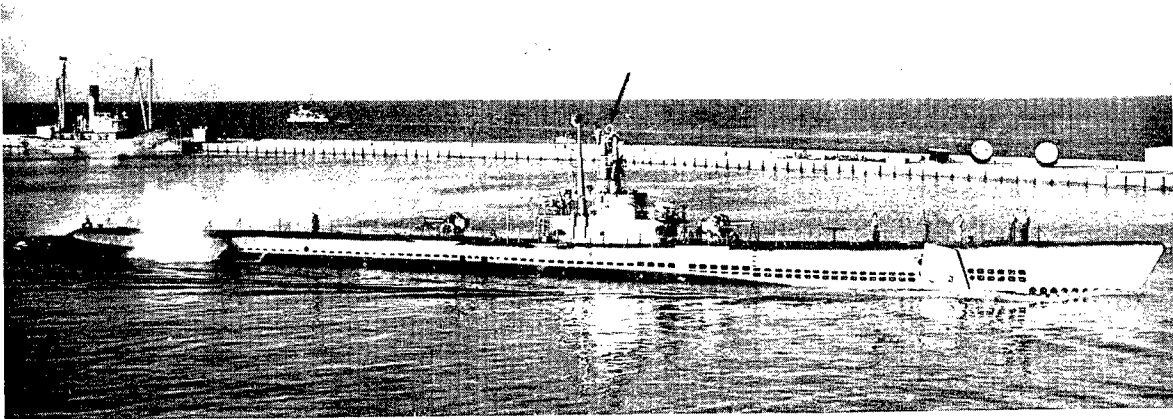


Fig. 1 - U.S.S. Sea Leopard with Remounted Receiving Loop.

the remounted loop was approximately 49 feet above the submarine keel. Since loop operation is normally limited to frequencies less than 80 kc/sec, a modification of the loop coupling unit was necessary to make "band three" cover 169 kc/sec, the lowest frequency obtainable for the U.S.S. MEDREGAL transmission.

A second receiving antenna, of the horizontal-wire type, was also installed. The general plan of this antenna is shown on the Frontispiece. The antenna cable consisted of the 0.188-inch conductor and 0.68-inch diameter polyethylene dielectric of type RG-17/U transmission line. The trailing end of the conductor was insulated from the sea water. A 104-foot length of cable, the horizontal section, was given slightly positive buoyance by having air-filled flexible plastic tubing laced to it. A planing float was attached at the leading end of this section of cable for the purpose of establishing the depth of submergence of the cable, estimated at roughly $3/4$ foot, independently of the exact depth of the U.S.S. SEA LEOPARD. The tow and electrical lead-cable consisted of a 46-foot extension of the same cable secured to the whip antenna mounting bracket at the rear of the SS radar mast. Finally, about 23 feet of cable led to a special water-tight housing covering the antenna-trunk bowl insulator. Figures 2, 3, and 4 show the sealed end of the antenna cable, the planing float, and

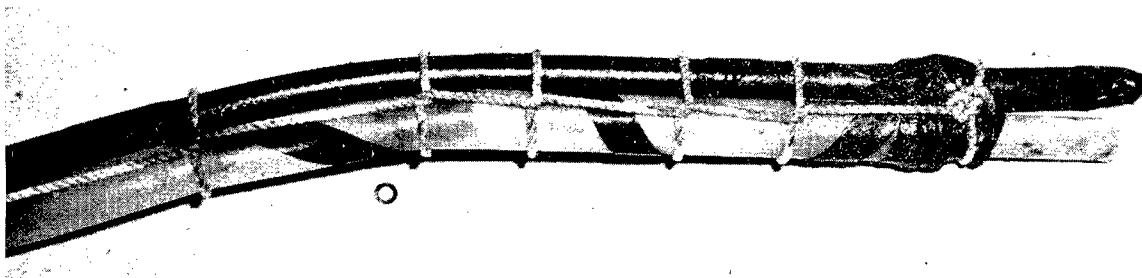


Fig. 2 - Trailing End of Antenna Cable with Tubing Attached for Buoyancy.

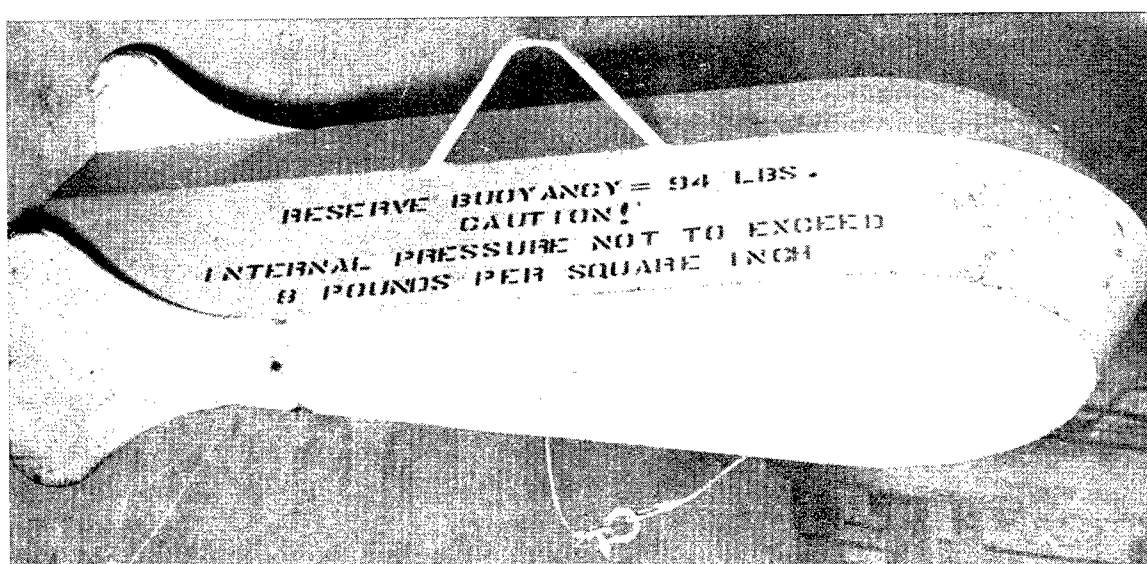


Fig. 3 - Planing Float Used for Antenna Depth Control.

the bowl insulator housing respectively. The whip antenna mounting bracket was about 44 feet above the keel.

On the U.S.S. MEDREGAL a horizontal-wire type antenna, similar to that on the U.S.S. SEA LEOPARD, was installed. The antenna cable consisted of the 0.25-inch conductor and 0.91-inch polyethylene dielectric type RG-19/U transmission line. The lengths of the horizontal, buoyant section, the "lead-tow" section, and the final lead section were 350, 50 and 20 feet, respectively. On the U.S.S. MEDREGAL the height of the whip antenna mounting bracket above the keel was approximately 43 feet. The total length of antenna cable was chosen on the basis of analyses, not yet reported, to be close to a quarter-wave long, in order to obtain reasonably good radiation and a simple "pattern".

The shorter U.S.S. SEA LEOPARD antenna was series-resonant at about 450 kc/sec, and the longer U.S.S. MEDREGAL antenna was similarly resonant

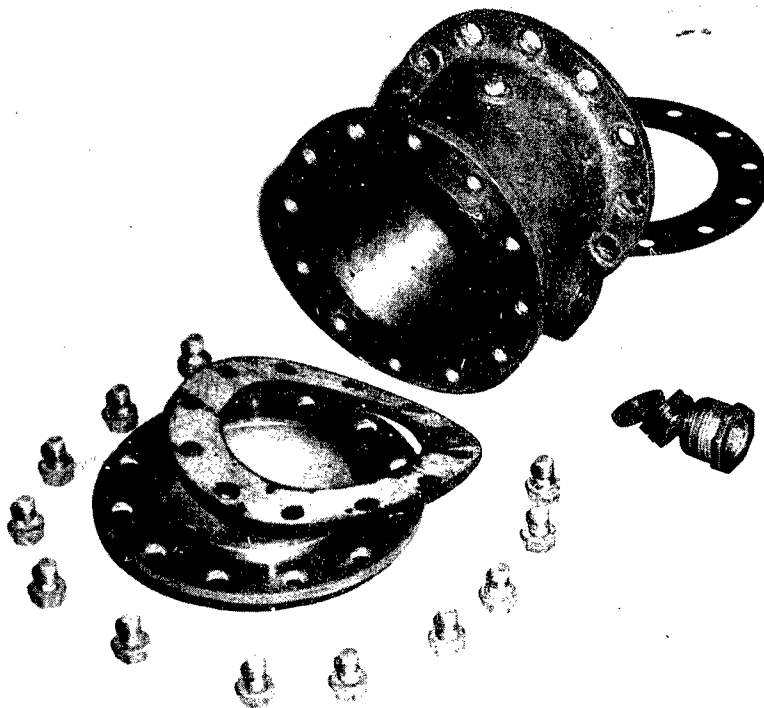


Fig. 4 - Water-tight Antenna Trunk Insulator Cover.

at about 190 kc/sec. Below the resonant frequencies, the antennas presented capacitive reactances, and no special matching circuits were required to couple either antenna to the Model TBL transmitter or to the Model RAK receiver.

OPERATIONAL AREA

An area 10,000 by 14,000 yards in extent, southwest of Key West, was assigned for the experiments. The area is located at $24^{\circ} 22\frac{1}{2}'$ N latitude and $82^{\circ} 1\frac{1}{2}'$ W longitude, where the depth of the sea is more than sufficient to permit complete submergence of submarines.

Since sea water is part of the radio propagation path, its electrical conductivity, in particular, is an important parameter determining the overall attenuation of the radiated signal. The measured conductivity at the sea water temperatures 27° and 27.7°C was 5.16 and 5.27 mhos/meter. These values are somewhat larger, due to the warmth of the water in the area, than the average sea water conductivity. The higher conductivity both increases the sea water attenuation and decreases the surface penetration by the radiation, thus making the condition of the experiments less favorable. Developments of these factors, attenuation and refraction (for reception), have been presented elsewhere.^{1,2} Either coefficient is the fraction of the field remaining after

¹ O. Norgorden, op. cit.

² R.B. Quinn and O. Norgorden, "The Transmission of Radio Signals from a Submerged Antenna," NRL Report R-3006, 6 November 1946

TRANSMISSION BETWEEN TWO SUBMARINES

For the actual operational experiment it was decided to use the horizontal wire antenna for reception on the U.S.S. SEA LEOPARD instead of the loop, largely for mechanical and operational reasons. The useful length of the U.S.S. MEDREGAL antenna was 350 feet; that of the U.S.S. SEA LEOPARD, 105 feet. After the necessary preliminaries in connection with the pattern measurements had been concluded, both submarines submerged, except for their periscopes, the U.S.S. SEA LEOPARD following the U.S.S. MEDREGAL at a gradually increasing distance from the original 500-yard separation. The input voltage to the receiver on the U.S.S. SEA LEOPARD was measured continuously as the range between the two vessels increased. When the distance separating the two vessels was 3000 yards the test was stopped because the level of the desired signal was weaker than the noise. Although it was not practical to make precise measurements, the data were sufficiently accurate to show that the field strength was inversely proportional to the range. This is what one would expect for the propagation of low frequency radio waves over sea water for relatively short ranges.

During the course of the range test the periscopes of both submarines were lowered simultaneously beneath the surface at intervals to check the possibility of transmission occurring between the raised periscopes. No effect on the strength of the received signal was observed, indicating that the periscopes were not acting as antennas.

It is desired to emphasize that the purpose of the experiment was to demonstrate the feasibility of submerged radio communication for very limited ranges and was not for the purpose of obtaining the maximum communication range. Actually the study of underwater radio has not progressed to the extent where it is possible to determine the fundamental limitations of such a system. Until a more complete understanding of the fundamental limitations of underwater radio systems is obtained, it does not appear unduly optimistic to predict that significant increase in range may be obtained by the application of logical improvements. An increase in transmitter output power, particularly if pulse techniques can be employed, is one direct method to secure increased range. This can be further supplemented by designing transmitting and receiving antennas of optimum efficiency and developing receivers especially for underwater radio applications. Finally, selection of the optimum frequency for transmissions of this type should be possible when sufficiently comprehensive data are available for analysis.

CONCLUSIONS

The experiment has shown that radio communication between two completely submerged submarines is possible over limited distances. The fact that no special transmitting, receiving or antenna coupling equipment was available and that optimum design of antennas or choice of frequency was not possible at the time, permits the assumption that future extension of ranges is practical.

the corresponding effect. For this conductivity, 3/4-foot submergence, and 169 kc/sec, the attenuation coefficient is 0.65 and the refraction coefficient 0.00134.

RECEPTION AND TRANSMISSION CHECKS

It is important in an operational experiment of this kind to insure that the results obtained are valid. In this particular case it was necessary to insure that the radio energy was radiated by the transmitting antenna and collected by the receiving antenna. The possibility of some portion of the submarine structure, other than the antennas, acting as the radiator or collector must be eliminated.

The radiation pattern in the horizontal plane for a submerged loop antenna or horizontal wire antenna, under the conditions of the experiment, is a "figure eight," with the maximum in the vertical plane of the loop or horizontal wire. On the other hand the radiation pattern in the horizontal plane from a simple vertical radiator is circular. Thus simple pattern measurements are useful in determining the validity of the experiments.

Pattern measurements were made on the transmitting horizontal-wire antenna on the U.S.S. MEDREGAL used both as a radiator and as a collector. For the receiving experiment, the submarine turned in a tight circle with the antenna completely submerged. A distant transmitting station was tuned in and the antenna output voltage (receiver input voltage) was monitored continuously. The minimum signal was below the noise level of the receiver and could not be measured. This minimum signal was, however, more than 10 db below the maximum signal and was in the proper direction.

For the transmission pattern measurements, the completely submerged horizontal wire antenna was excited by the submarine's Model TBL transmitter operating on 169 kc. The field above the surface was measured on board an aviation rescue craft, the AVR-30. The AVR-30 circled the submarine, which was submerged except for the periscope, at approximately a constant range. Field intensity measurements were made as continuously as possible and it was determined that the minimum signal was 13 db below the maximum. The maximum signal was in the proper direction.

Receiving pattern measurements were made on the type 66097 loop and horizontal-wire antenna on the U.S.S. SEA LEOPARD under conditions similar to those employed during the U.S.S. MEDREGAL reception experiments. A satisfactory ratio of maximum to minimum signal was obtained.

The results of the foregoing tests demonstrated quite conclusively that the power was radiated by the horizontal-wire antenna and was collected by the loop or horizontal-wire antenna respectively during the transmission and reception experiments.

It was shown that the sea-water-to-air-to-sea-water propagation path for radio waves does occur. The distance was far too great for the transmission to have taken place entirely within the attenuating sea water path from transmitter to receiver. Further, no appreciable transmission could have occurred directly between the two antennas because of the collinear disposition. The field strength in the intermediate part of the propagation path, namely air, was of value to be reasonably expected.

ACKNOWLEDGMENT

The interest, ready cooperation, and substantial assistance of U. S. Submarine Squadron Four very greatly facilitated the prosecution of these underwater radio experiments. Acknowledgment is due particularly to Captain L. R. Daspit, Commanding Officer of Squadron Four, to Commanders S. Filippone and G. H. Whiting, Commanding Officers of the U.S.S. SEA LEOPARD and the U.S.S. MEDREGAL, and to Lieutenant W. M. Rand, Electronic Officer of the U.S.S. HOWARD W. GILMORE. Commander T. H. Suddath, Commanding Officer of the Naval Ordnance Unit, Key West, gave great assistance in the loan of facilities and in arrangements for the cooperation of Squadron Four. The planing floats were made available for the experiment through the courtesy of the David Taylor Model Basin.

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